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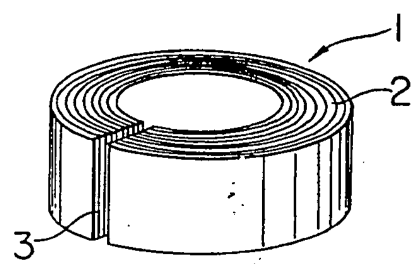
(54) **Amorphous wound coil**

(57) An amorphous wound core 1 for use in a normal-mode noise filter or an output smoothing device, comprises a gap 3. The wound core is impregnated with a resin such as an epoxy resin. The wound core has good DC current superimposition characteristics and high complex permeability. It may be produced by the steps of winding an amorphous alloy ribbon, heat-treating the resulting wound core, coating it with resin, providing a gap therein, placing a non-magnetic spacer in the gap, and coating the core surface with insulating resin.

FIG. 1



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The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

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FIG. 1

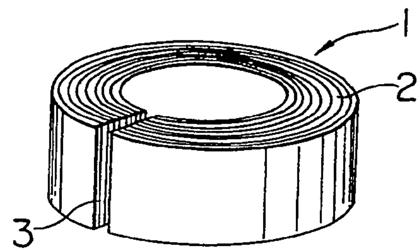


FIG. 2

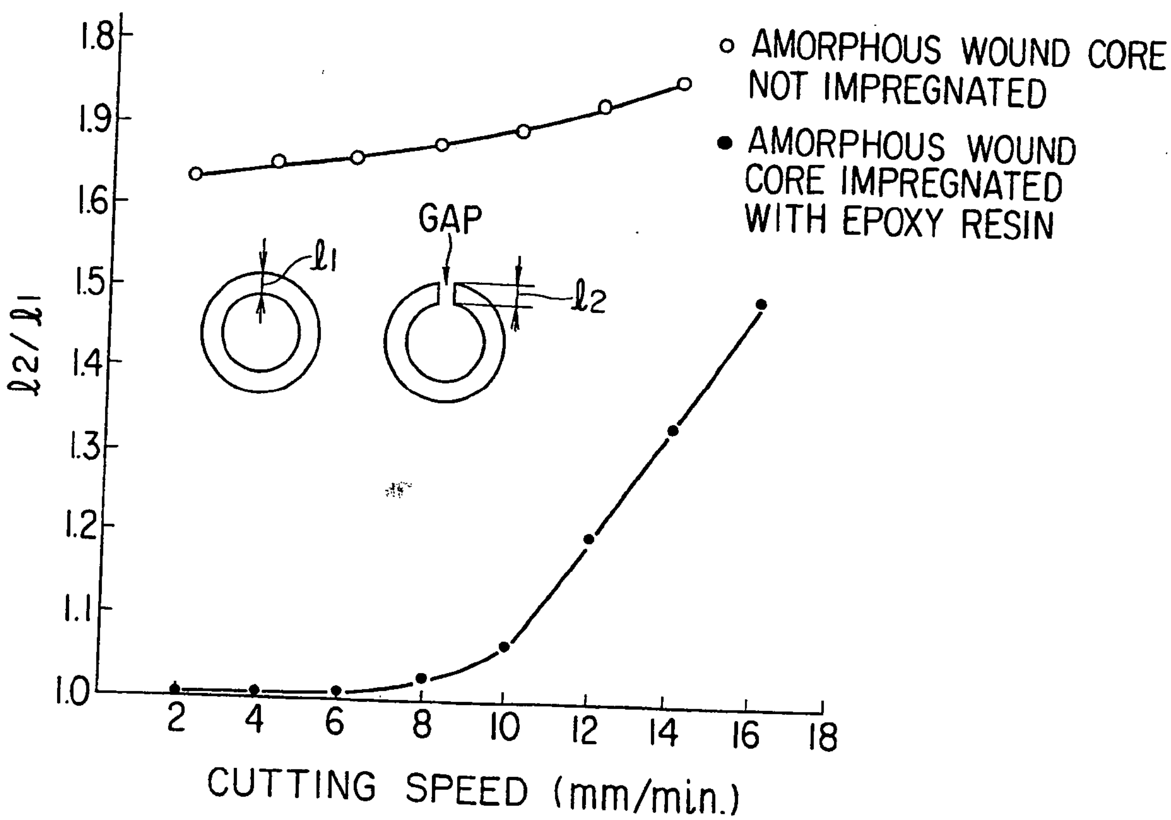


FIG. 3

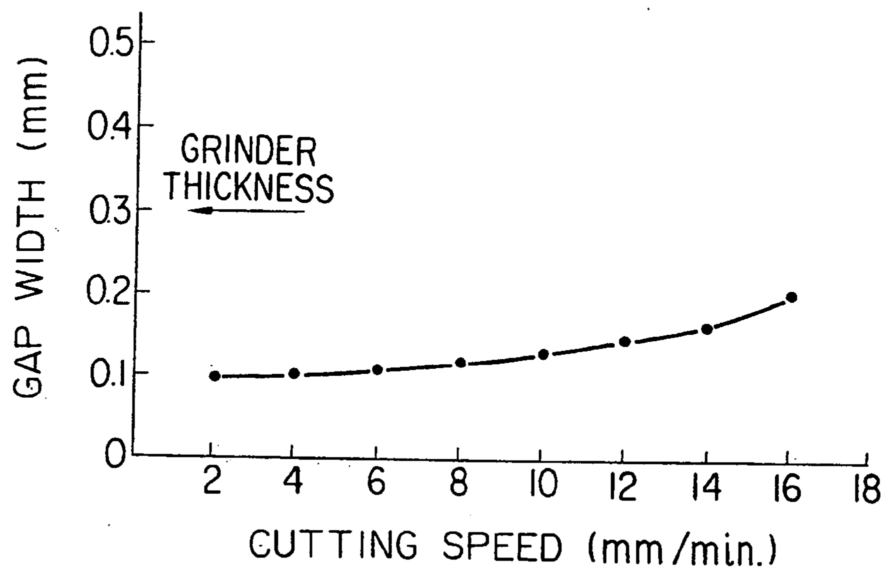

0.5
0.4
0.3
0.2
0.1
0
GAP WIDTH (mm)
GRINDER
THICKNESS
2
4
6
8
10
12
14
16
18
CUTTING SPEED (mm/min.)

FIG. 4

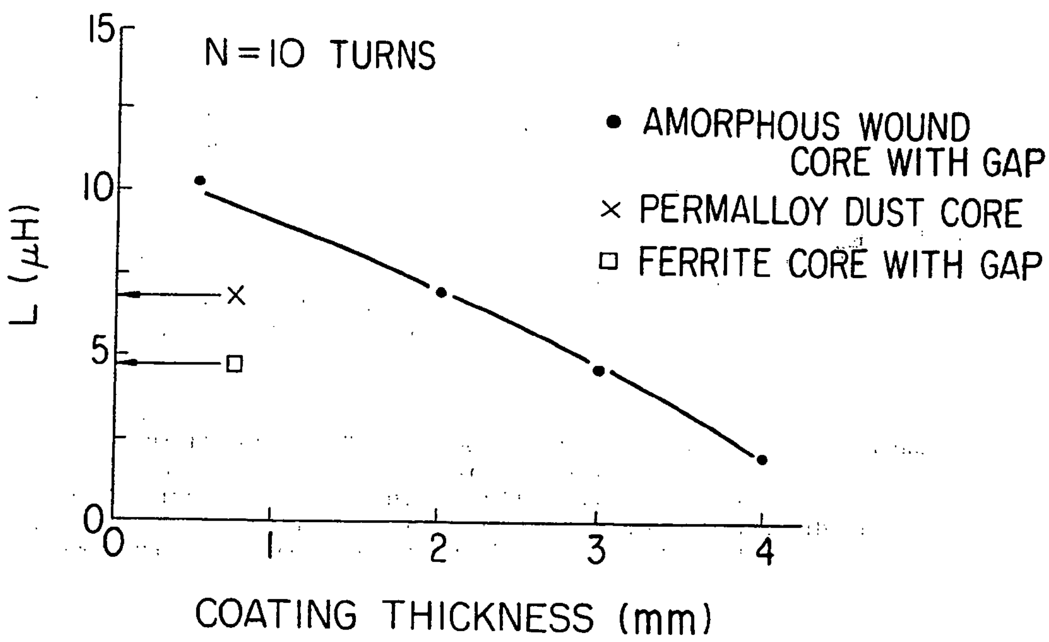

15
10
5
0
L (μH)
N=10 TURNS
• AMORPHOUS WOUND CORE WITH GAP
× PERMALLOY DUST CORE
□ FERRITE CORE WITH GAP
0
1
2
3
4
COATING THICKNESS (mm)

FIG. 5

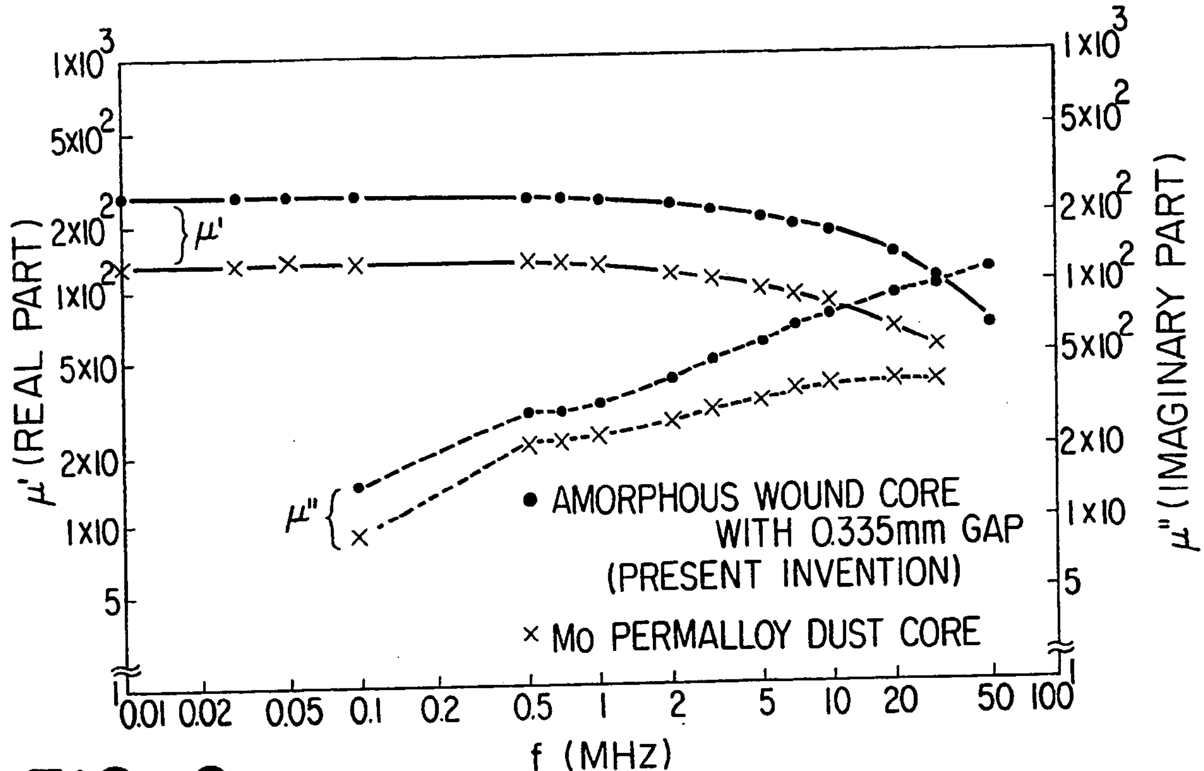

1x10^3
5x10^2
2x10^2
1x10^2
5x10
2x10
1x10
5
1
μ' (REAL PART)
μ'' (IMAGINARY PART)
μ'
μ''
• AMORPHOUS WOUND CORE WITH 0.335mm GAP (PRESENT INVENTION)
× Mo PERMALLOY DUST CORE
0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 50 100
f (MHz)

FIG. 6

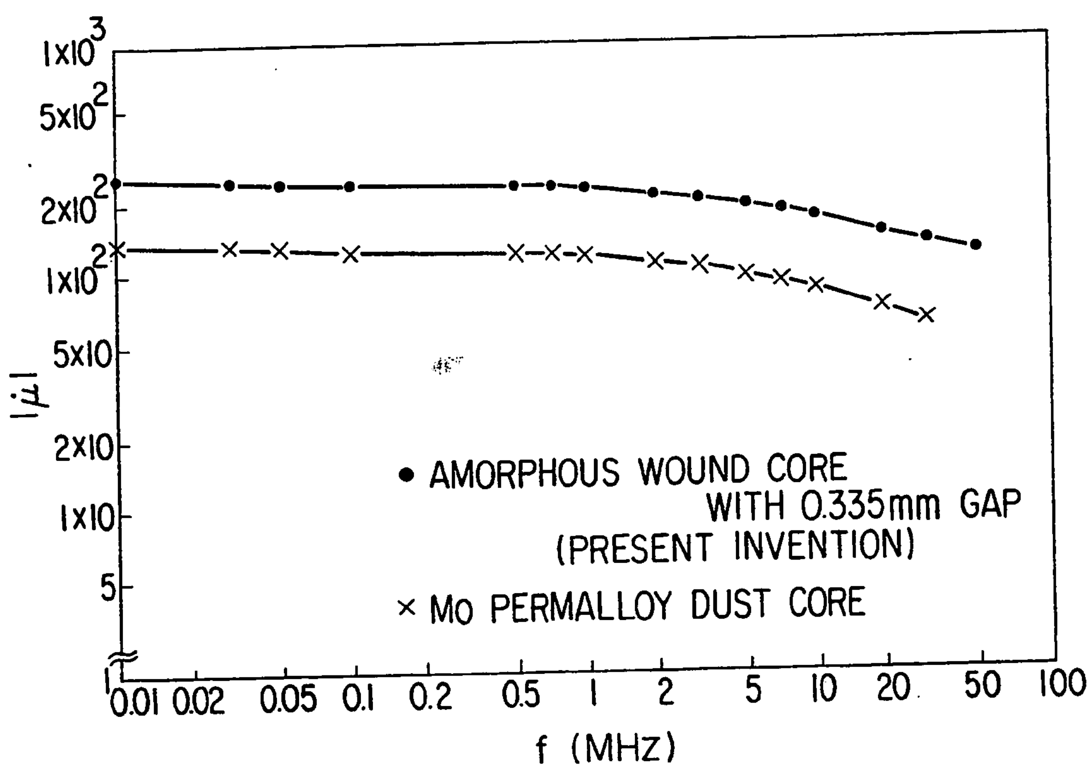

1x10^3
5x10^2
2x10^2
1x10^2
5x10
2x10
1x10
5
1
|μ|
• AMORPHOUS WOUND CORE WITH 0.335mm GAP (PRESENT INVENTION)
× Mo PERMALLOY DUST CORE
0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 50 100
f (MHz)

FIG. 7

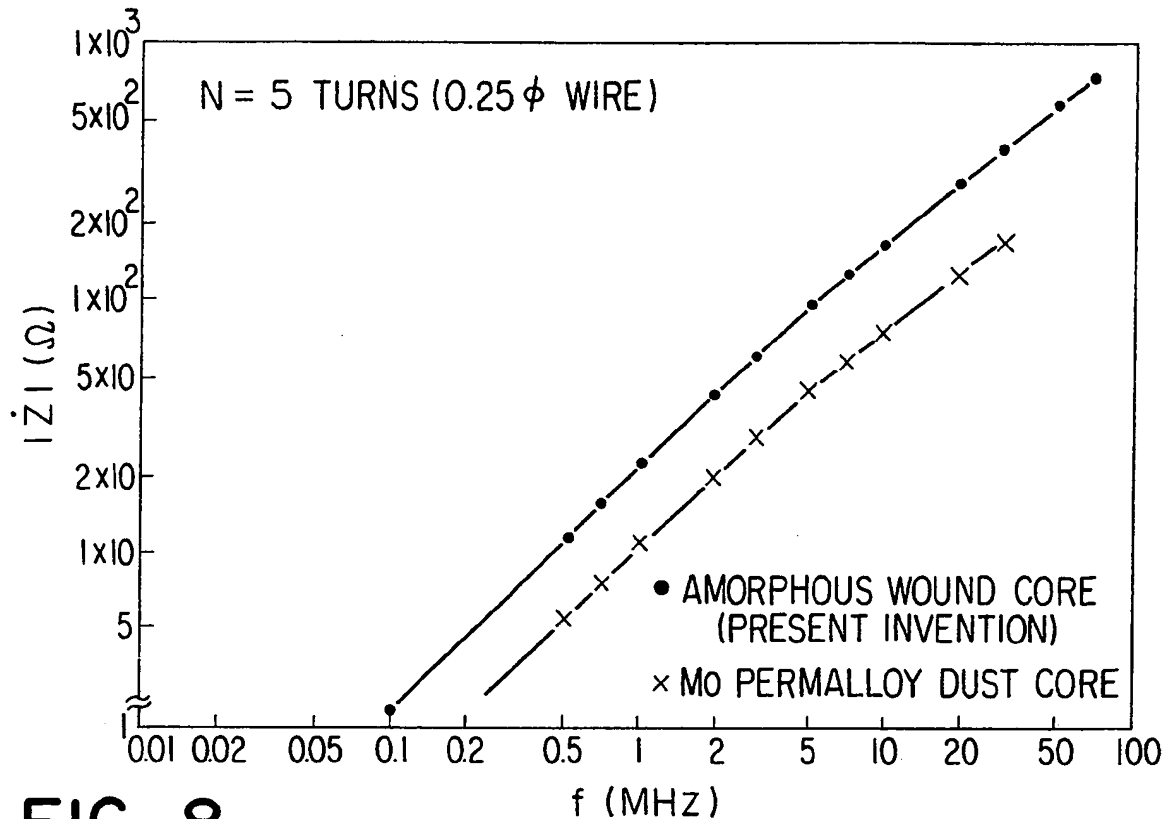

N = 5 TURNS (0.25 φ WIRE)
1x10^3
5x10^2
2x10^2
1x10^2
5x10
2x10
1x10
5
1
|Ż| (Ω)
0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 50 100
f (MHz)
• AMORPHOUS WOUND CORE (PRESENT INVENTION)
× Mo PERMALLOY DUST CORE

FIG. 8

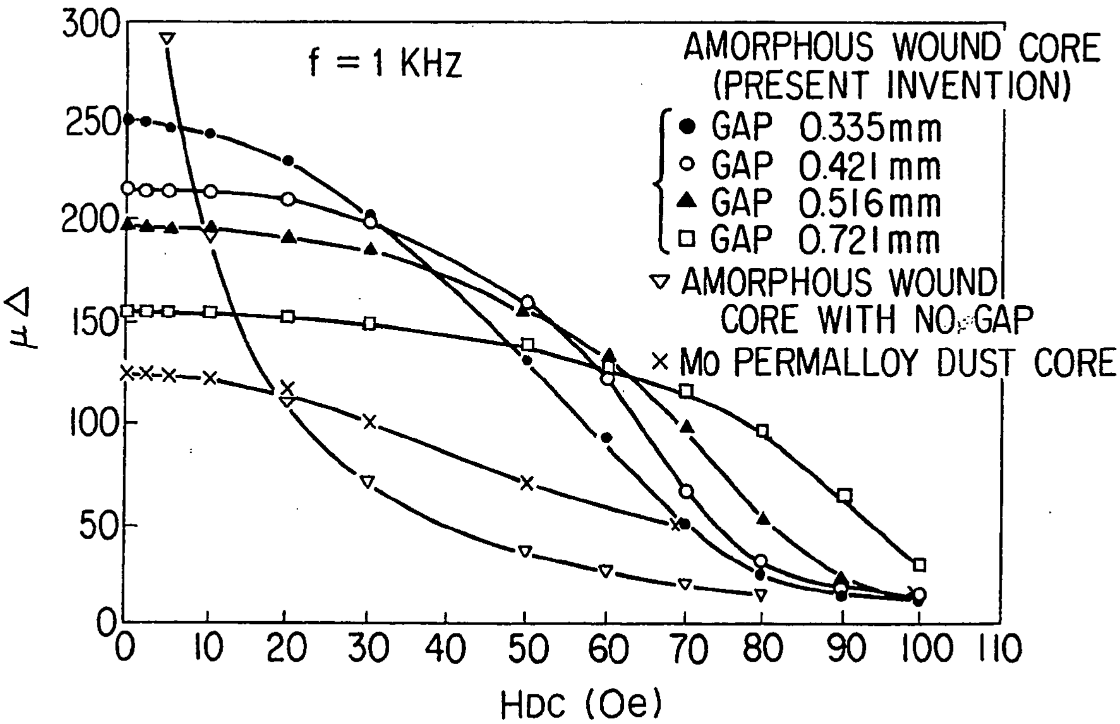
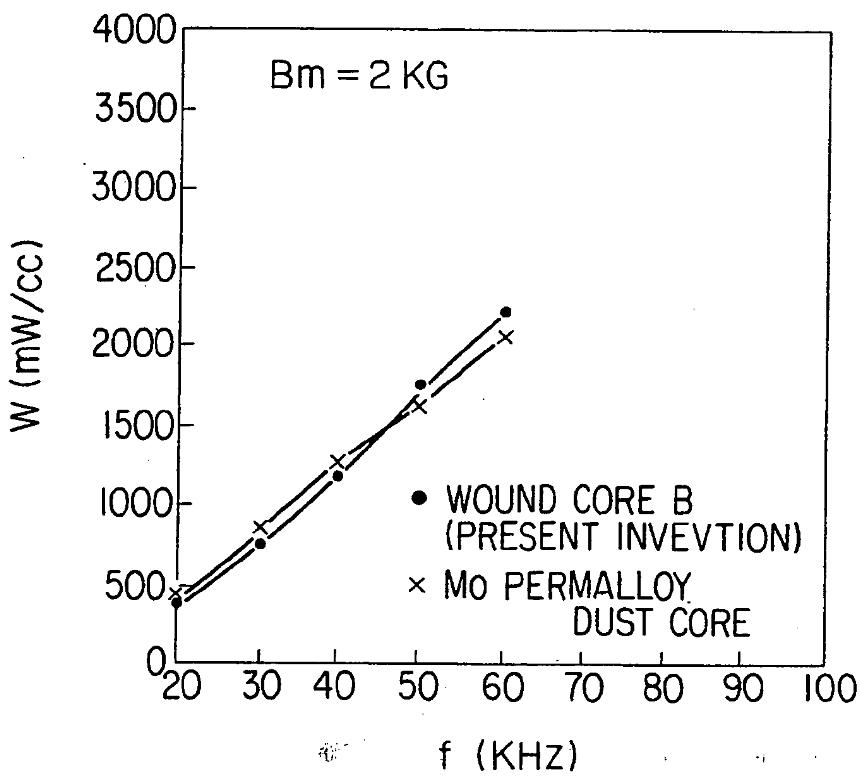

f = 1 KHz
300
250
200
150
100
50
0
μΔ
0 10 20 30 40 50 60 70 80 90 100 110
HDC (Oe)
AMORPHOUS WOUND CORE (PRESENT INVENTION)
• GAP 0.335mm
○ GAP 0.421mm
▲ GAP 0.516mm
□ GAP 0.721mm
▽ AMORPHOUS WOUND CORE WITH NO GAP
× Mo PERMALLOY DUST CORE

FIG. 9


Bm = 2 KG
W (mW/cc)
4000
3500
3000
2500
2000
1500
1000
500
0
20
30
40
50
60
70
80
90
100
f (KHz)
● WOUND CORE B
(PRESENT INVEVTION)
× Mo PERMALLOY
DUST CORE

SPECIFICATION

Amorphous wound core

Background of the invention

(1) Field of the invention

The present invention relates to an amorphous wound core with a gap which is suitable for normal-mode noise filtering and output smoothing.

(2) Description of the prior art

Because of recent development of electronic apparatuses, switching power supplies have been getting more and more widely used. As a result, output smoothing chokes and normal-mode noise filters have become widely used.

Choke magnetic cores are conventionally made of sintered ferrites, silicon steel ribbons, permalloy dust cores, etc. Recently, the use of amorphous magnetic cores for chokes has been proposed. Dust cores do not raise any problem of noise because of no gap, and are relatively good in frequency characteristics. They have, however, low permeability so that they are not necessarily satisfactory when used for chokes because of low impedance.

Ferrite cores have as low as about 5000 G of staturation magnetic flux density Bs, so gaps are needed to provide sufficient saturation magnetic field. This, however, lowers the apparent permeability of the cores, resulting in chokes with poor magnetic characteristics. In addition, ferrite cores are inferior to dust cores in frequency characteristics. Silicon steels suffer from large core loss.

Amorhous cores have higher saturation magnetic flux density Bs than that of ferrite cores. Amorphous cores are also advantageous over silicon steel cores in core loss, though the former has lower Bs than that of the latter.

Japanese patent Laid-Open Nos. 57-82454 and 57-83005 disclose wound cores made of an amorphous Fe-Ni-Si-B alloy and an amorphous Fe-Co-Si-B alloy, respectively. These amorphous wound cores, however, do not have any gap, so their permeabilities drop rapidly as a magnetic field increases. This tendency is not suitable where they are used for normal-mode noise filters and output smoothing devices.

Summary of the invention

An object of the present invention is to provide an amorphous wound core useful for normal-mode noise filters and output smoothing devices, which has good direct current superimposition characteristics and good frequency characteristics of impedance.

Another object of the present invention is to provide such an amorphous wound core with excellent gap precision. An amorphous wound core according to the present invention comprises at least one gap.

The amorphous wound core is impregnated with a resin so that it may keep its shape and dimension after being provided with a gap. The gap may be filled with a non-magnetic spacer. The resin-impreganted wound core may be further coated with a non-conductive resin to insulate it from a conductive wire wound on the core.

Brief description of the drawings

Figure 1 is a perspective view of an amorphous wound core according to one embodiment of the present invention;

Figure 2 is a graph showing the relation between the cutting speed with a grinder and the thickness change of the amorphous wound core after being provided with a gap;

Figure 3 is a graph showing the relations between the cutting speed with a grinder and the gap width of the amorphous wound core;

Figure 4 is a graph showing the relations between the coating thickness and inductance of the amorphous wound core provided with a gap;

Figure 5 is a graph showing complex permeabilities of magnetic cores varying depending on frequency;

Figure 6 is a graph showing the absolute values of the magnetic cores' conplex permeabilities varying depending on frequency;

Figure 7 is a graph showing the absolute values of the complex impedance of choke coils varying depending on frequency;

Figure 8 is a graph showing the relations between a bias DC magnetic field combined with an AC magnetic field and the incremental permeabilities of magnetic cores; and

Figure 9 is a graph showing the frequency dependence of the core loss of magnetic cores.

Description of the preferred embodiments

Referring to Figure 1, an amorphous wound core 1, which is constituted by an amorphous alloy ribbon 2, comprises a gap 3.

Any amorphous alloy having a high saturation magnetic flux density Bs may be used according to the present invention. Iron-base amorphous alloys are particularly desirable because of a high saturation

magnetic flux density Bs. Iron-base amorphous alloys which may be used in the present invention include those defined by the general formula: $Fe_dNi_eT_fSi_gB_h$ wherein T represents one or more elements selected from the group consisting of Be, Mg, Ca, Sr, Ba, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Ru, Co, Pd, Cu, Zn, Y, Ce, Pr, Nd, Sm, Eu, Gd, Tb and Dy, $d + e + f + g + h = 100$, $72 \leqq d+e \leqq 85$, $0.05 \leqq e/(d + e) \leqq 0.40$, $0 \leqq f \leqq 3$, $7<g<16$, $7<h<10$, $15 \leqq g+h \leqq 25$.

Specific examples of these iron-base amorphous alloys are $Fe_{70}Ni_8Si_{13}B_9$, $Fe_{63}Ni_{15}Si_{13}B_9$, $Fe_{54}Ni_{24}Si_{13}B_9$, $Fe_{78}Ni_5Si_8B_9$, $Fe_{70}Ni_8Ti_3Si_{11}B_8$, $Fe_{68}Ni_7Cr_2Sr_1Si_{14}B_8$, etc. See Japanese patent Laid-Open No. 57 82454.

Another example of Fe-base amorphous alloys which may be used are defined by the general formula: $Fe_dCO_eT_fSi_gB_h$ wherein T represents one or more elements selected from the group consisting of Be, Mg, Ca, Sr, Ba, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Ru, Ni, Pd, Cu, Zn, Y, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, $d + e + f + g + h = 100$, $72 \leqq d + e \leqq 85$, $0.05 \leqq e/(d + e) \leqq 0.70$, $0 \leqq f \leqq 3$, $7<g<16$, $7<h<10$, $15 \leqq g + h \leqq 25$. Specific examples are $Fe_{78}Co_5Si_8B_9$, $Fe_{70}Co_8Si_{13}B_9$, $Fe_{63}Co_{15}Si_{13}B_9$, $Fe_{54}Co_{24}Si_{13}B_9$, $Fe_{39}Co_{39}$-$Si_{13}B_9$, etc. See Japanese Patent Laid-Open No. 57-83005. These Fe-base alloys provided magnetic wound cores having excellent DC current superimposition characteristics because of their high saturation magnetic flux density. Amorphous alloys are used in the form of a ribbon 2. The ribbon 2 is wound until the core thickness reaches a desired level. The amorphous alloy ribbon 2 may be produced by any known method.

The amporphous wound core 1 may be heat-treated to enhance magnetic characteristics thereof. The heat treatment is performed by annealing the wound core 1 at temperatures of about 250°C to about 450°C and cooling it at the rate of less than about 300°C per hour. A magnetic field may be applied in the heat treatment, if necessary. The magnetic wound core 1 is provided with a gap 3. In the embodiment as shown in Figure 1, the gap 3 extends throughout a vertical cross section of the wound core 1. The gap 3, however, may be in any form and dimension in general. It may have a uniform width or may be tapered. The gap 3 is provided by cutting operations with a grinder. The width of the resulting gap is not necessarily equal to the thickness of the grinder used, but tends to be smaller than the latter due to slight deformation of the wound core after cutting. The gap width may vary depending on a cutting speed. The radial thickness of the wound core 1 may also vary depending on the speed of cutting to provide a gap to the core.

The gap 3 may be filled with a non-magnetic spacer to ensure its dimensional stability. The non-magnetic spacer may be made of plastics, aluminium, etc.

The amorphous wound core 1 is solidified with resins so that it may keep its desired dimension and shape after being provided with a gap. The solidification of the wound core with resins may be performed by impregnating it with liquid resins, which may include liquid monomers or oligomers, polymer solutions in organic solvents, molten resins, etc. the resins which may be used include thermoplastic resins and thermosetting resins. When thermosetting resins are employed, they may preferably contain curing agents. A liquid epoxy resin containing an appropriate curing agent and an inorganic varnish are preferable for the purpose of solidifying the wound core.

When a liquid epoxy resin containing a curing agent is used, the wound core is first immersed in the resin liquid, placed in a vacuum chamber to make the resin liquid infiltrate into the innermost part of the core while removing air bubbles from it, and then heated at temperatures of about 85°C to about 100°C to cure the epoxy resin. Inorganic varnishes are also useful because they can easily infiltrate into the wound core. The wound core is immersed in an inorganic varnish and then heated at temperatures of about 100°C - about 150°C, preferably about 120°C.

The solidification of the wound core 1 with resins may also be achieved by coating the surface of an amorphous ribbon 2 with resins, winding the ribbon 2 to form a core, and then heating the wound core 1. Resins for coating may also be thermoplastic or thermosetting resins. The amorphous wound core 1 may be further coated with non-conductive resins. The surface coating of the core should be so thick as to ensure the insulating of the core from wires wound thereon. With respect to a space factor, however, the surface coating should have a restricted thickness. Therefore, the insulating resin coating may be generally as thick as about 0.5 mm to about 2 mm.

In the preferred embodiment, the amorphous wound core 1 may be produced by winding the amorphous alloy ribbon 2 into a toroidal shape; subjecting the resulting toroidal wound core to an appropriate heat treatment; impregnating it with resins; providing it with a gap 3; placing a non-magnetic spacer in the gap 3; and coating the core surface with insulating resins.

The present invention will be further explained by the following Examples.

Example 1

An $Fe_{Ba1}Ni_{7.5}Si_{16}B_9$ alloy melt was ejected through a thin nozzle onto a copper roll rotating at a high speed to form a thin amorphous ribbon of about 20 μm in thickness and about 6.5 mm in width. The amorphous ribbon was wound to form a toroidal core of 20 mm in outer diameter, 12 mm in inner diameter and 6.5 mm in height. The toroidal core was immersed in an EPIKOTE (trade name for epoxy resin) solution containing a curing agent, placed in a vacuum chamber to remove air bubbles and then heat-cured. The epoxy resin-impregnated wound core was cut with a grinder to have a gap, resulting in the wound core as shown in Figure 1.

Example 2

With respect to the wound core 1 produced as in Example 1, measurements were conducted to know how the thickness of the wound core changes by cutting it to provide a gap 3 by means of a grinder having a 0.3-mm thickness at various cutting speeds. Also, to evaluate the effects of resin impregnation on the thickness change of the wound core, the same measurements were carried out on both of the wound core impregnated with EPIKOTE and that not impregnated. The results are shown in Figure 2. Figure 2 shows that at the cutting speed of up to about 10 mm/min., there is substantially no thickness change of the wound core impreganted with the resin. On the other hand, the core not impregnated suffered from a large thickness change at any cutting speed.

Example 3

With respect to the wound core 1 produced as in Example 1, measurements were conducted on the width of the gap 3 provided by a 0.3 mm-thick grinder at various cutting speeds. The results are shown in Figure 3. It is shown that the gap 3 was narrower than the grinder thickness, and that the gap width gradually increased as the cutting speed increased.

Example 4

The amorphous wound core produced as in Example 1, which is saturated at 100 Oe, was subjected to surface coating with an insulating resin (EPIKOTE), and a conductive wire was wound 10 turns thereon. The inductance of the wound core was measured at various surface coating thickness. The results are shown in Figure 4. The inductance gradually decreases as the coating becomes thicker. To have a good space factor, thus high inductance, the coating should be less than about 2 mm. It is to be noted that the amorphous wound core 1 having a surface coating of less than 2 mm has higher inductance than those of a permalloy dust core without a gap and a ferrite core with a gap.

Example 5

The amorphous wound core 1 having a 0.335-mm gap produced as in Example 1 was measured with respect to complex permeability at various frequencies. The real part μ' and imaginary part μ'' of the complex permeability are shown in Figure 5 in comparison with those of the Mo permalloy dust core. It is noted that the amorphous wound core of the present invention has a higher imaginary part μ'' of the complex permeability, which means that it works well particularly for normal-mode noise filtering.

Figure 6 shows the absolute value of the complex permeability $|\mu|$ of the above amorphous wound core in comparison with that of the Mo permalloy dust core. It is observed that the resin-impregnated amorphous wound core having a 0.335-mm gap has substantially constant $|\mu|$ over a wide range of frequency, well higher than $|\mu|$ of the Mo permalloy dust core. This means that the permeability of the amorphous wound core of the present invention has very good frequency characteristics.

Example 6

Five turns of a wire of 0.25 ϕ was wound on the above amorphous wound core to form a choke, and the resulting choke was measured with respect to impedance. Figure 7 shows the absolute value of the complex impedance $|z|$ of the above amorphous wound core over a wide range of frequency, in comparison with that of the Mo permalloy dust core. It is appreciated that the amorphous wound core has higher $|z|$ than that of the Mo permalloy dust core throughout the frequency range measured.

Example 7

The effects of a gap width on DC current superimposition characterictics will be evaluated. The following five amorphous wound cores with various gap widths were measured together with the Mo permalloy dust core with respect to incremental permeability $\mu\Delta$.

Amorphous Wound Core*	Gap Width (mm)
A	–
B	0.335
C	0.421
D	0.516
E	0.721

*All of them were produced in the same way as in Example 1.

The incremental permeability $\mu\Delta$ is defined by the following expression:

$$\mu\Delta = \frac{1}{\mu_0} \left(\frac{\Delta B}{\Delta H}\right)$$

wherein ΔB and ΔH are respectively incremental magnetic flux density and incremental magnetic field when an AC magnetic field is superimposed on a certain level of a DC magnetic field.

Measurements were conducted using a bias DC magnetic field ranging from 0 to 100 Oe with an AC magnetic field having a one-KHz frequency. The results are shown in Figure 8.

It is seen that the amorphous wound core with a gap has a incremental permeability $\mu\Delta$ which is higher than that of the Mo permalloy dust core and does not drop rapidly with the increase of HDC. The amorphous wound core with no gap has a very high incremental permeability $\mu\Delta$ at a low HDC (less than 10 Oe), but is $\mu\Delta$ drops rapidily as the HDC increases. This fact shows that the amorphous wound core with a gap according to the present invention has good DC current superimposition characteristics which are necessary for a normal-mode noise filter choke and output smoothing device.

Example 8

Core loss was measured on the amorphous wound core B of the present invention as well as on the Mo permalloy dust core. The results are shown in Figure 9. It is found that the amorphous wound core with a gap according to the present invention has as good frequency characteristics of core loss as that of the dust core. As mentioned above, the amorphous wound core with a gap according to the present invention has good DC current superimposition characteristics and high complex permeability. Therefore, it is highly suitable for normal-mode noise filtering and output smoothing.

The present invention has been described above with reference to the preferred embodiments, but it is to be noted that the present invention is not restricted by them and that it may be modified and changed without departing from the spirit and scope of the present invention.

CLAIMS

1. An amorphous wound core comprising at least one gap.
2. An amorphous wound core according to Claim 1, wherein said core is impregnated with a resin.
3. An amorphous wound core according to Claim 2, wherein said gap is filled with a non-magnetic spacer.
4. An amorphous wound core acording to Claim 1, wherein said core is made of an Fe-base alloy.
5. An amorphous wound core according to Claim 2, wherein said resin-impregnated core is further coated with an insulating resin.
6. An amorphous wound core according to Claim 5, wherein the insulating coating of said resin-impregnated core has a thickness of less than about 2 mm.
7. An amorphous wound core according to Claim 5, wherein said gap is covered with a thin metal sheath.
8. A method of producing an amorphous wound core, comprising the steps of: winding an amorphous alloy ribbon to form a toroidal core; impregnating the wound core with a resin to solidify said wound core; and providing a gap to said resin-impregnated wound core.
9. A method of producing an amorphous wound core according to Claim 8, further comprising the step of heat treatment after the step of winding the amorphous alloy ribbon.
10. A method of producing an amorphous wound core according to Claim 8 or 9, further comprising the step of placing a non-magnetic spacer in the gap after the step of proving the gap.
11. A method of producing an amorphous wound core according to Claim 10, further comprising the step of coating the core surface with an insulating resin.
12. A method of producing an amorphous wound core according to Claim 9, wherein said heat treatment comprises annealing the wound core at temperatures of about 250°C - about 450°C and cooling it at the rate of less than about 300°C per hour.
13. A method of producing an amorphous wound core according to Claim 12, wherein the annealing is conducted in a DC or AC magnetic field.
14. A normal-mode noise filter comprising a resin-impregnated amorphous wound core provided with a gap.
15. An output smoothing device comprising a resin-impregnated amorphous wound core provided with a gap.

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